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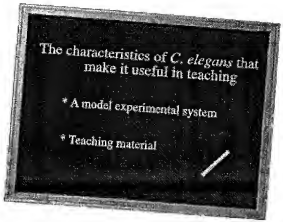


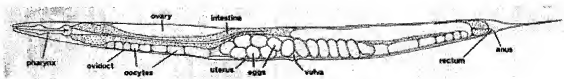
The Characteristics of *C. elegans* That Make It Useful in Teaching

Dr. Sydney Brenner

In 1963, Sydney Brenner observed that the success of molecular biology was due to the existence of model systems, defined as extremely simple organisms, such as bacterial phage that can be handled in large numbers. With the awareness of how important model systems are in biological research, he introduced *Caenorhabditis elegans* (*C. elegans*) as a model organism for pursuing research in developmental biology and neurology. Ever since its introduction by Brenner, *C. elegans* has been widely used in research laboratories (Wood, 1988). Due to its value as a research tool, a sophisticated knowledge infrastructure has developed, with freely disseminated research methods and protocols. The experimental attributes of *C. elegans* that make it successful in research laboratories also make it a favorable organism in teaching. Below, I will discuss the characteristics that make *C. elegans* so popular in research. I will explore the properties that make it useful to biology education, as well.

A Model Experimental System: Properties of C. elegans

Caenorhabditis elegans (*Caeno*, recent; *rhabditis*, rod; *elegans*, nice), is a free-living, non-parasitic soil nematode that can be safely used in the laboratory and is common around the world (Donald, 1997).

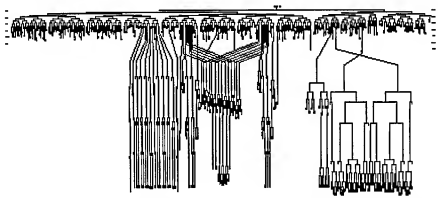


Up: Hermaphrodite, Down: Male. Notice the difference between their tail.

It is small (about 1 mm in length), transparent for ease of manipulation and observation, feeds on bacteria, such as *E. coli*, and it can be easily and cheaply housed and cultivated in large numbers (10,000 worms/petri dish) in the laboratory. *C. elegans* has five pairs of autosomes and one pair of sex chromosome. It has two sexes, hermaphrodites and males. Sexual determination in *C. elegans* is similar to *Drosophila*; the ratio of sex chromosomes to autosomes determines its sex. If the 6th chromosome pair is XX, then *C. elegans* will be a hermaphrodite. A XO combination in the 6th chromosome pair will produce a male. Hermaphrodites can self-fertilize or mate with males but cannot fertilize each other. In nature, hermaphrodites are the most common sex. When hermaphrodites mate with males, 50% of the progeny will be males and 50% will be hermaphrodites. In the laboratory, self-fertilization of hermaphrodites or crossing with males can be manipulated to produce progeny with desired genotypes that are especially useful for genetic study. In addition, *C. elegans* is extremely fecund-a hermaphrodite can produce about 300 to 350 offspring under self-fertilization and more if it mates with males. These traits make it easy to produce numerous genotypes and phenotypes for genetic research. (Donald, 1997; Horvitz, 1997; Wood, 1988).

In addition, *C. elegans* has a short life cycle. From egg to egg takes about 3 days, about the same time needed for genetic crosses in yeast. Its life span is around 2 to 3 weeks under suitable living condition. Compared to the use of other model organisms, such as mice, the short life cycle of *C. elegans* reduces the experimental cycle and facilitates biological study (Donald, 1997; Kenyon, 1988; Wood, 1988).

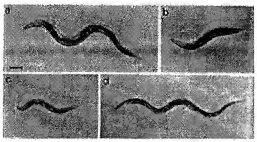
What is unique to this organism is that wild-type individuals contain a constant 959 cells. The position of cells is constant as is the cell number. Moreover, it is transparent. It is easy to track cells and follow cell lineages. The complete cell lineage, depicting which cells are derived from which, was completed in the 1980s by John Sulston. This provides a great tool for research on how genes influence cell fate. These traits enable the study of the biology of a single cell in an intact, living organism. Research on development and morphology can be done with a single cell within this multicellular organism (Donald, 1997; Horvitz, 1999; Kenyon, 1988; Wood, 1988).



The complete *C. elegans* cell lineage (from top to down. It is possible to know which cell is derived from which. The rapid early division are embryonic)

The genome size of *C. elegans* is about a hundred million base pairs. This is approximately 20X bigger than that of *E. coli* and about 1/30 of that of human. The genome of *C. elegans* was completely sequenced at the end of 1998 (BBC, 1998). It is the first multicellular-organism (animal) that has a completely sequenced genome. Robert Waterston noted the value of this accomplishment when he said, "This is a tremendously gratifying moment and more of a beginning than an end. We have provided biologists with a powerful new tool to experiment with and learn how genomes function. We'll be able to ask-and answer questions we could never even think about before." Moreover, as its genome is

surprisingly similar to that of humans (40% homologous), *C. elegans* becomes an attractive organism in the study of human diseases. For instance, in human leukemia, large numbers of immature white blood cells (WBCs), which normally die before getting into the blood stream, are in patients' blood circulation. The study of Programmed Cell Death (PCD, or apoptosis) in *C. elegans* might help us to understand why these immature WBCs didn't undergo PCD. In addition, the genome database of *C. elegans* is available worldwide. Researchers share their findings in *C. elegans* genome via the internet with other researchers from around the world. The process of sharing the genome database on the world wide web provides a working framework for researchers who are working on the human genome project (Ahringer, 1999; BBC, 1998; HGP, 1999; Hodgkin, Horvitz, Jasny, & Kimble, 1998; Horvitz, 1999; Kenyon, 1988; Muhlrad, 1998; Pennisi, 1998).



Various mutants, a.normal, b.dummpy, c.small, d.long

Moreover, there are many *C. elegans* mutants available for biological research, which is especially important for genetic study. Some genetically determined traits, such as motility mutants, are easy to observe. Therefore, powerful genetic experiments can be conducted using simple microscopes to observe the inheritance of traits in *C. elegans* mutants. When a mutant is found, it can be crossed with worms having a known genetic background and, further, one can learn where this mutated gene may be located and define its function.

In 1969, John Sulston developed a technique to freeze and thaw the worm. As a result, the numbers and availability of both wild type and mutated worms have increased (Donald, 1997). Moreover, many tools have been invented to speed up research using *C. elegans*. Advanced microscopes, various antibodies, different kinds of reporter genes for labeling and the use of laser microbeams to ablate individual cells are examples of such tools (Donald, 1997; Kenyon, 1988; Wood, 1988).

Dr. John Sulston

C. elegans is a model experimental organism that possesses simplicity, is small in size physically and genomically. It is multicellular and develops from a fertilized egg to an adult worm just as a human being does (Angier, 1995; Donald, 1997). In conclusion, the properties of *C. elegans* and the research done using *C. elegans* provide a wealth of information and an attractive pool of resources for researchers. Also, this well-established model system provides educators a good resource in teaching biology.Top

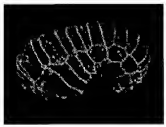
Teaching Material: Available Resources of C. elegans for Teaching

C. elegans has grown in its popularity in the classroom. At the 12th *C. elegans* Meeting held at the University of Wisconsin-Madison in 1999, several educators presented their uses of *C. elegans* as an educational model. The reasons they use *C. elegans* in teaching are similar to why biologists use *C. elegans* as a model system in research.

This small worm is paving its way in educational use due to its short life cycle, its small size, its transparent body, its ease of cultivation, its ability to be crossed at will and the similarity of its genome to that of the human. In addition to these advantages, the available resources, such as the stock of mutants, the completion of its genome sequence, and various advanced tools, make it easy to use *C. elegans* in classrooms.

Being able to house *C. elegans* and culture it in the classroom is the first step to use it in teaching. It is also a good model organism for students to watch animal behavior, because *C. elegans* shows a diversity of behaviors. It can taste, smell, and sense light and temperature. These characteristics make *C. elegans* a good experimental organism for students to study behavior (Aamodt, 1999; DeStasio, 1999).

Large numbers of mutant stocks make it an attractive teaching material as well. It is easy to get a mutated worm with a desired trait. For example, motional defective worms can be used to teach muscle physiology or for students to understand how mutations influence a worm's phenotype. Various mutagens can be used to produce mutants. For instance, ethylmathanesulforate (EMS) is a mutagen that induces direct mutations in DNA, such as missense and nonsense mutations. In teaching genetics, the selection of mutants is essential and EMS can be used to treat *C. elegans* to produce desired mutants (Miller, 1999; Morgan, 1999b; Sulcove & Allen, 1999).



Labeled using GFP to show cell junction (Click to see the movie. 1.6 MB). Note: this link will lead you to another web site.

The discovery of reporter genes can be used to show when and where a protein is expressed that implies the expression of a gene. The green fluorescent protein (GFP) reporter gene is a gene cloned from jellyfish. It can be fused to a piece of DNA and expressed with that gene. By observing the worm with the green fluorescent protein under a microscope, the expression of a gene can be seen, and its timing, location and quantity of the gene expression can be monitored (Aroian, Johnson, & Wienhausen, 1999; Miller, 1999; Morgan, 1999b). In addition, the invention of advanced microscopes and the completion of the complete *C. elegans* cell lineage are good for teaching development. Generally speaking, the motility of *C. elegans* can be observed by using dissecting microscopes. However, by using advanced microscopes, such as Nomaski optics, students can observe the process of development and morphogenesis in a single cell (Miller, 1999).

Available molecular techniques are useful to help students learn more advanced topics. For instance, the Polymerase Chain Reaction (PCR) can be used to detect the existence of a specific gene in *C. elegans*. Chemical reagents, such as colchicine, an alkaloid toxic, which interrupts cell division at mitosis, can be used to study cell division and development (Lissemore, Lackner, & Fedoriw, 1999; Miller, 1999).

As more resources become available for a model experimental system, its success as an educational model increases. As Robert Waterston said, the completion of *C. elegans* genome is a start rather than an end in the biological research, thus, it is predictable that there will be more discoveries based on the use of *C. elegans* that will make it a more attractive model organism in the curriculum.Top

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Image credits

1. Dr. Sydney Brenner (Leon Avery, 10/27/1997, http://elegans.swmed.edu/Sydney.html)

2. Hermaphrodite and male: Wood, W. B. (Ed.). (1988). The nematode *Caenorhabditis elegans*. New York, NY: Cold Spring Harbor Laboratory Press.

3. various mutants (Brenner, S. (1974). The Genetics of Caenorhabditis elegans. Genetics, 77, 71-94.)

4. completion of genome (Science, 1998, vol 282, 2011)

5. Dr. John Sulston (The Sanger Centre, 12/26/1999, http://www.sanger.ac.uk/Users/jes/)

6. cell lineage (Kenyon, C. (1988). The Nematode *Caenorbabditis elegans*. Science, 240, 1448-1452.)

7. GFP labeled (Loci, 6/15/1999, http://www.loci.wisc.edu/optical/ows.html)

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